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AUTOMATING PAN EVAPORATION MEASUREMENTS FOR IRRIGATION CONTROL*

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ABSTRACT

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Class A pan evaporation measurements are reasonable estimates of evapotranspiration in humid climates when soil water is not restricting plant growth. With the development of high-frequency irrigation systems where small quantities of water are applied often to replace evapotranspiration losses, frequent automatic water-level measurements are essential and can be used to control an irrigation system.

A class A pan evaporation measurement and control instrument was developed to automatically measure pan evaporation with electronic analog or digital recording equipment. The instrument was a LVDT with a stainless-steel float adapted to a standard cylindrical stilling well.

Measurement sensitivity of 4.542 ± 0.001 V cm^{-1} of evaporation and range of 5 cm was obtained with an input voltage of 24 V dc. The instrument's time response was 130 sec to a step change in water level of 0.27 cm. Automatic measurements obtained during a windstorm (average gusts of wind at 48 km h^{-1}) indicated that this instrument could measure pan evaporation more precisely under adverse wind conditions when simultaneous manual measurements with the hook gauge were not possible.

This instrument plus an electronic soil matric potential sensor was used in the field to control a high-frequency porous tube subirrigation system. Our results indicated that this control method could maintain the fluctuation of the soil matric potential in the root zone within a narrow range.

INTRODUCTION

Potential evapotranspiration of growing crops can be estimated with evaporation pans by using appropriate predetermined constants (Pruitt, 1966). Agroclimatic procedures for measuring water-budget effects on crop yield were reviewed by Stanhill (1962, 1973), and Linacre and Till (1969), who indicated that measurements of open-water surface evaporation were usually required. Parmele and McGuinness (1974) showed that in humid climates

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class A pan evaporation measurements were reasonable estimates of evapotranspiration when soil water was not restricting plant growth.

Water evaporation from pans is measured conventionally with hook micrometers (Holtan et al., 1968) as frequently as desired, depending upon the intended use of the data. For high-frequency irrigation systems (Rawlins, 1973; Phene et al., 1973), small quantities of water are applied to replace evapotranspiration losses, so frequent automatic water-level measurements are essential. If suitable pan factors are available (Doorenbos and Pruitt, 1975) an open-water surface-evaporation measurement instrument can be used to control automatically an irrigation system.

This paper describes an accurate, rapid-response, high-resolution controlling and measuring instrument, which utilizes the output voltage of a linear variable differential transformer (LVDT) connected to a float mounted in a stilling well to measure evaporation in pans.

DESIGN AND CONSTRUCTION

The water-level sensor (Fig.1) consists of a LVDT (Trans-Tek model 244—000, Trans-Tek Inc., Route 83, Ellington, Connecticut, 06029)*, a standard cylindrical stilling well, a spherical stainless-steel float, and a head assembly for positioning and protecting the LVDT. Fig.2 shows the system's components assembled ready for installation in the U.S. Weather Bureau (USWB) class A evaporation pan or other types of pans.

The LVDT (with 24-V dc input voltage) is combined in an integrated package, with a solid state oscillator and phase-sensitive demodulator. The linear displacement of the core within the coil produces a dc voltage change, linearly related to the displacement of the core. The voltage change can be measured accurately with a dc voltmeter, recorder and/or used to drive a relay-meter as a control system. The maximal linear displacement range of this LVDT is ± 2.54 cm with linearity of ± 0.5% of full scale and an infinite resolution. LVDT's with greater ranges are commercially available and can be substituted easily, but the water level in the pan should not fluctuate more than 5 cm, since a low water level in the pan could affect evaporation rate by increasing air turbulence above the pan.

The input dc voltage supply to the LVDT was connected to two terminals, and a digital voltmeter or a strip chart recorder can be used individually or simultaneously to measure and record the output voltage of the LVDT from the other two terminals. A relay-meter with adjustable set points can also be used to control an irrigation system and to maintain a given water level in the pan.

The standard cylindrical stilling well is 8.9 cm in diameter and is levelled with adjusting screws. The stilling well was connected to the water in the pan

*Trade names are used for identification purposes only and do not imply preference for this item by the U.S. Department of Agriculture.

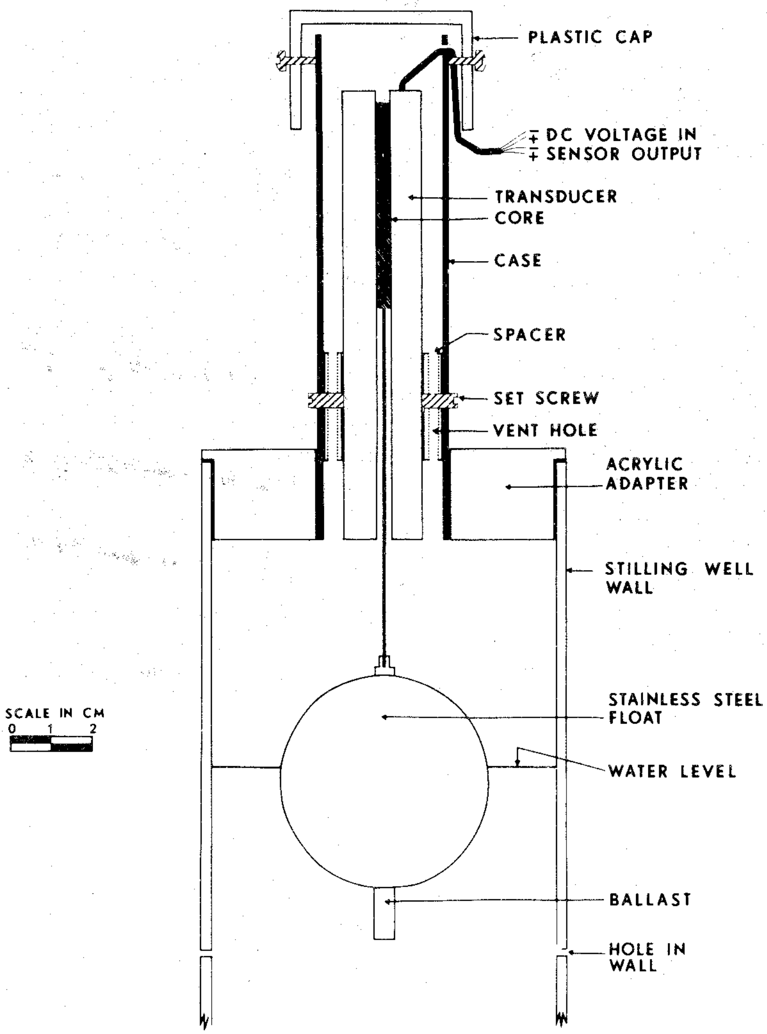

Fig.1. Electronic float sensor mounted on a stilling well for automatic measurements of evaporation in pans.

by two or three holes, 0.12 cm in diameter, in the vertical wall near the bottom of the well, through which water could flow to adjust to the level of the pan. The hole at the bottom of the standard well casing had to be sealed, since it was much too large to damp oscillations of the water within the stilling well.

A spherical stainless-steel float, 5 cm in diameter, (Chicago Float Works, 230 Scott Street, Elk Grove Village, Ill., 60007) was attached to the stem of the core of the LVDT. A 22.4-g lead ballast was attached to the bottom

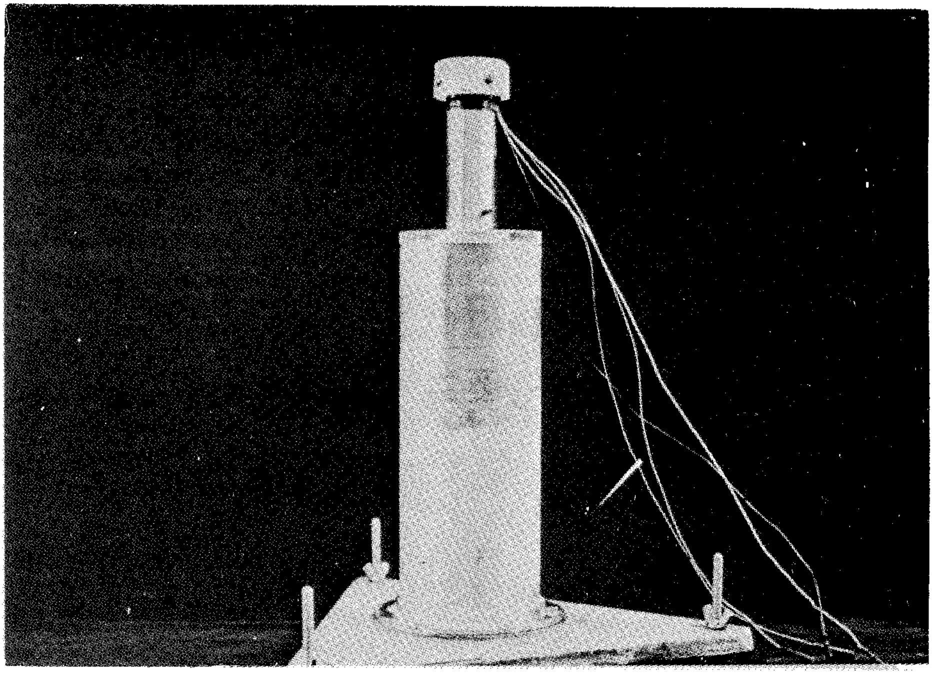

Fig.2. Assembled components of standard USWB class A evaporation pan automated LVDT measurement system.

of the float to lower its center of gravity and dampen its oscillatory motion. The LVDT was inserted into the protecting head assembly and positioned above the water with two screws which are also used to adjust the vertical position of the sensor to give an output voltage corresponding to the range of pan water levels to be measured. This system was calibrated and used in evaporation pans to measure hourly evaporation with an electronic soil sensor to control a high-frequency irrigation system (Phene, 1974).

PERFORMANCE AND CHARACTERISTICS

The voltage output of the system was calibrated as a function of the water level in the USWB class A evaporation pan by adding and removing aliquots of water and calculating the change in level by dividing the volume of water added or removed by the surface area of the pan. The regression line obtained for these calibration points, when a 24-V dc input voltage was used, showed that this sensor had a sensitivity of 4.542 ± 0.001 V cm^{-1}. The correlation coefficient of the regression line obtained by measuring 10 levels within the range of the LVDT was 0.99995. Half of the levels were measured while water was being added to the pan and half while water was being removed from the pan, thus eliminating effects of any possible hysteresis of the system on calibration.

The time response of the instrument to continuous evaporation and to an incremental change in water level was determined for the addition and removal of water from the pan. For a 0.27-cm step change in water level the time response of the sensor was 2 min ± 10 sec (Fig.3). We performed this test in the morning when the pan evaporation rate was negligible. This time

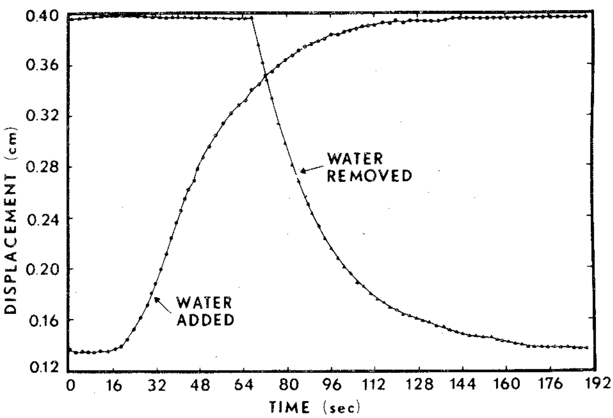

Fig.3. Time response of the sensor to a 0.27-cm increase and decrease in pan water level.

constant provides sufficient damping and eliminates water level fluctuations in the well caused by winds or vibrations that would affect the accuracy. The time constant of the system can be adjusted by inserting a tapped screw to elongate the holes, by changing the diameter of the holes drilled into the side wall of the stilling well, or by adjusting the mass of the ballast at the bottom of the float (Fig.1). The combination used showed that pan evaporation could be accurately measured during windy periods when hook gauge measurements could not be made.

Figs.4 and 5 show rapid measurements of the water level in the pan under field conditions when the wind was blowing at an average speed of 8.2 and 48 km h^{-1}, respectively. Regression lines fitted to these data are shown on each figure. Fig.4 shows that for 67 measurements at 2.5-sec intervals, the standard error of estimate (SEE) under normal wind conditions (8.2 km h^{-1}) was 0.0008 cm, when the evaporation rate was 0.1188 cm h^{-1}, or approximately 0.67% error. Hook gauge measurements under similar conditions showed that the percent error was 10 times greater. Fig.5 shows that for 87 measurements at approximately 10-sec intervals during a thunderstorm, the SEE at wind gusts averaging 48 km h^{-1}, was 0.0044 cm, when the evaporation rate was 0.011 cm h^{-1}, or approximately 40% error. During this period we could not obtain hook gauge measurements because the water level fluctuated rapidly in the stilling well.

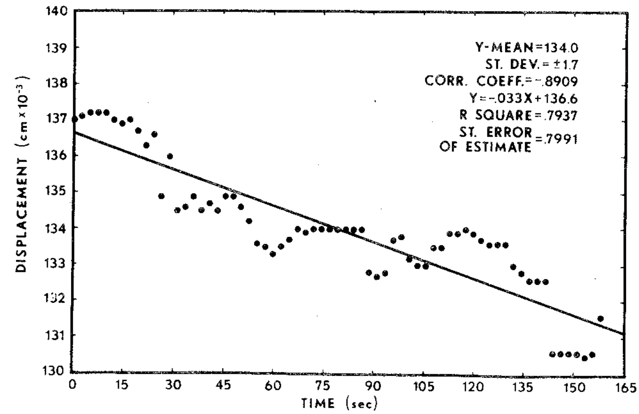

Fig.4. Rapid field measurements of the water level in a standard USWB class A evaporation pan in gusts of wind up to 8.2 km h^{-1} (normal wind conditions).

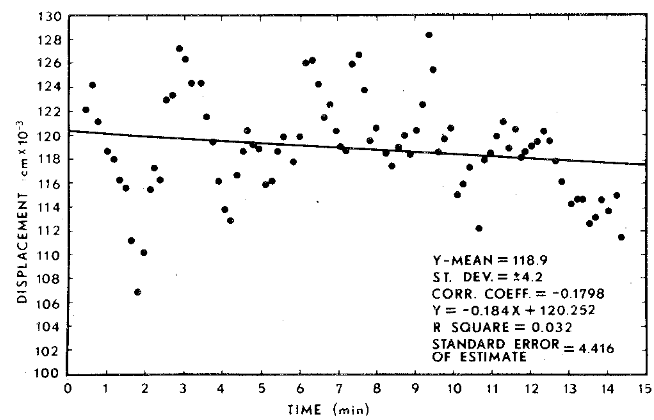

Fig.5. Rapid field measurements of the water level in a standard USWB class A evaporation pan in gusts of wind up to 48 km h^{-1}.

FIELD TEST

An open evaporation pan was installed in the field over grass with an automated LVDT measurement system and a stilling well for hook gauge measurements. Measurements were recorded half-hourly with a digital data acquisition system and five consecutive hook gauge measurements were recorded daily. The calculated mean of the hook gauge measurements of daily evaporation was compared with the 48 half-hourly measurements obtained with the automated LVDT sensor. Days with rainfall were eliminated to simplify the evaluation procedure. Short- and long-range performances of the two instruments were compared.

Fig.6 is a graph of a typical 24-h comparison of water evaporation measurement from the pan with the hook gauge and the automated LVDT sensor system. The 24-hourly measurements of pan evaporation are accumulated for a total of 0.45 cm. After 24 h, we noted no significant difference between evaporation measurements from both instruments. The mean hook gauge measurement after 8 h differs from that from the automated LVDT sensor by 0.05 cm.

Table I and Fig.7 show daily comparisons of pan evaporation as a function of time from Julian day 84 to 126, measured automatically with the LVDT and manually with the hook gauge. In Fig.7, the measurements obtained by either method are in close agreement. Table I shows that the daily percent difference between the two methods of measurements is variable, but that

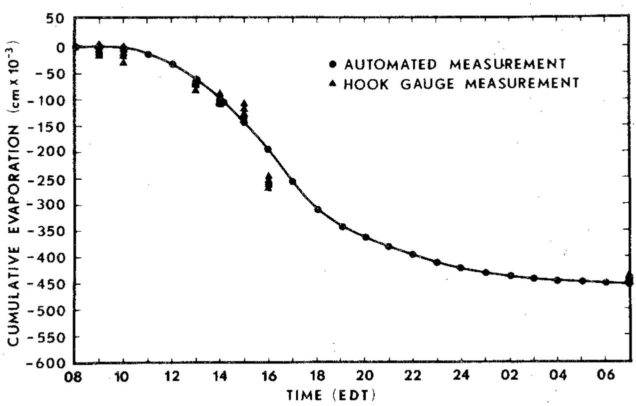

Fig.6. Automated and hook gauge measurements of water evaporation from a standard USWB class A pan for a 24-h period.

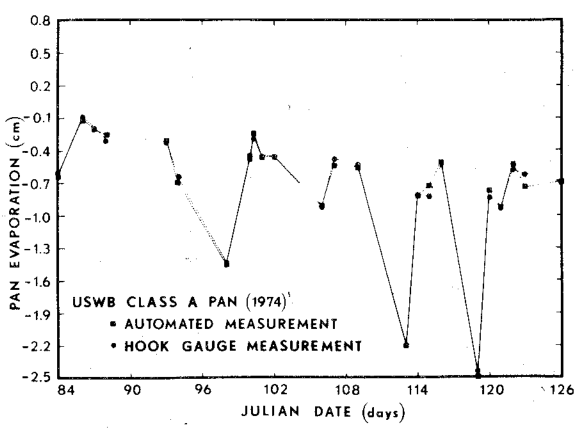

Fig.7. USWB class A evaporation pan measurements obtained with the hook gauge and the LVDT system.

TABLE I

USWB class A pan evaporation measurements

Julian dates	No. of days	Open pan evaporation (cm)		Absolute % difference between automated and manual measurements
		automated measurement	manual measurement	
84	1	−0.615	−0.595	3.3
86	1	−0.097	−0.078	19.6
87	1	−0.193	−0.177	8.3
88	1	−0.251	−0.296	15.2
93	1	−0.298	−0.291	2.3
94	1	−0.687	−0.638	7.1
96—98	3	−1.452	−1.420	2.2
100	1	−0.668	−0.748	10.7
101	1	−0.456	−0.441	3.3
102	1	−0.454	−0.451	0.7
106	1	−0.900	−0.918	2.0
107	1	−0.524	−0.472	9.9
109	1	−0.548	−0.527	3.8
110—113	4	−2.203	−2.195	0.4
114	1	−0.810	−0.804	0.7
115	1	−0.719	−0.822	12.5
116	1	−0.503	−0.518	2.9
117—119	3	−2.480	−2.426	2.2
120	1	−0.764	−0.827	7.6
121	1	−0.917	−0.928	1.2
122	1	−0.519	−0.571	9.1
123	1	−0.737	−0.621	15.7
126	1	−0.692	−0.686	0.9
Mean daily pan evaporation		−0.583	−0.582	mean: 6.2

the total evaporation for this 30-day period agreed within 0.2%. This difference was greatest when the hook gauge measurements were made on windy days. The range of the consecutive hook gauge measurements recorded at approximately 3-min interval for a 12-day period varied between 0.007 and 0.045 cm, with a mean value of 0.020 cm. The mean standard deviation and standard error for these 12 sets of five consecutive measurements were 0.008 cm and 0.004 cm, respectively.

The USWB class A pan with automated LVDT measurement system was used with an electronic soil matric potential sensor (Phene et al., 1973) to control high-frequency irrigation systems. Fig.8 shows the system's logic used for this experiment. The decision to irrigate was based on the simultaneous measurements of evapotranspiration estimated from the pan and from a soil matric potential measurement at 15 cm from the soil surface, as described by Phene (1974). Although the pan usually lags behind actual evapotranspiration

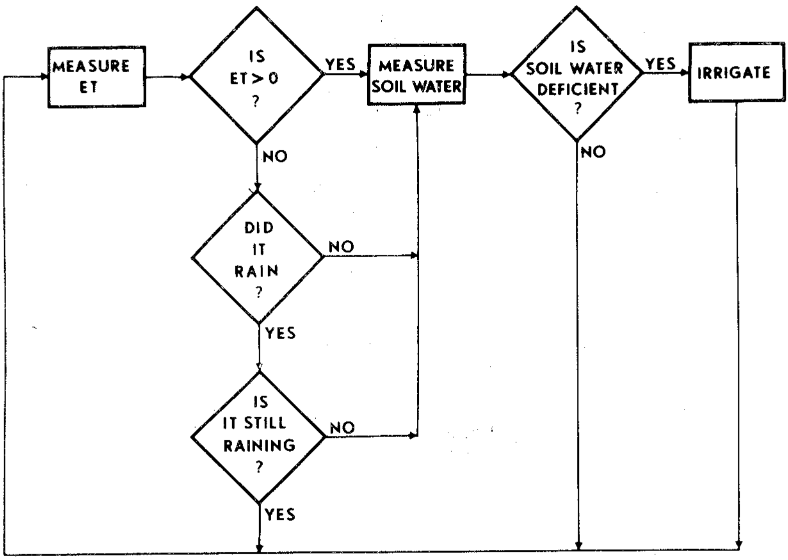

Fig.8. High-frequency irrigation control logic using a combination of standard USWB automated class A pan and soil matric potential measurements.

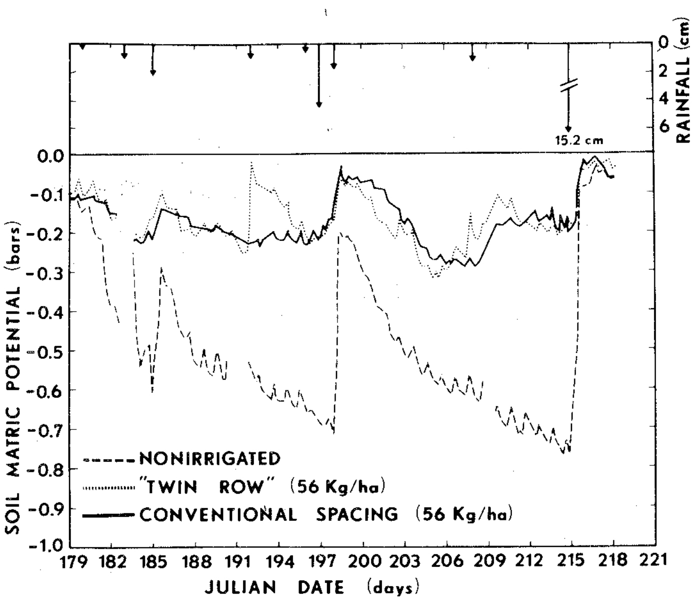

Fig.9. Soil matric potential at 15 cm from the soil surface in plots irrigated with high-frequency trickle irrigation systems controlled by combination of pan evaporation — soil matric potential systems and nonirrigated plots.

by 4 to 6 h, the daily totals agree and the soil matric potential sensor will initiate irrigations if the soil water is deficient. The amount of irrigation water applied was a function of the ratio of potential evapotranspiration to open pan evaporation and of the physiological age of the crop, as reported by Doss et al. (1962). However, if the soil matric potential was higher than the level set for irrigation, no irrigation cycle was initiated, thus optimizing water use.

Fig.9 shows the soil matric potentials, at 15 cm from the soil surface, for field plots of sweet corn with different row spacings, irrigated by high-frequency trickle irrigation systems. For comparison, soil matric potentials of nonirrigated plots are also shown. In this experiment, the minimal soil matric potential was maintained between —0.20 and —0.25 bar during the growing period by irrigating as often as 12 times daily, if necessary. The maximal range of soil matric potentials during that period was —0.78 bar for the nonirrigated plots, —0.30 bar for the irrigated "twin row" plots, and —0.27 bar for the irrigated conventional spacing plots.

CONCLUSIONS

A class A pan evaporation measurement and control instrument was developed to automatically measure pan evaporation with electronic analog or digital recording equipment. The instrument consisted of a LVDT with a stainless-steel float adapted to a standard cylindrical stilling well. Measurement sensitivity of 4.542 ± 0.001 V cm^{-1} of evaporation and range of 5 cm was obtained with an input voltage of 24 V dc. The instrument's time response to a 0.27-cm step change in water level was 130 sec. Automatic pan evaporation measurements obtained during a windstorm, with gusts of wind averaging 48 km h^{-1}, indicated that this instrument could perform adequately under adverse wind conditions which did not permit manual measurements with the hook gauge. Also automatic pan evaporation measurements were more precise than those simultaneously made with a hook gauge, especially during windy periods. This instrument was used in the field with an electronic soil matric potential sensor to control a high-frequency porous tube sub-irrigation system. Our results indicated that this control method could maintain the fluctuation of the soil matric potential in the root zone within a narrow range.

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